PROGRESS OF SPACE STUDIES

OF THE EARTH'S SURFACE, METEOROLOGY AND CLIMATE 1992 -1993

This report briefly summarizes the progress made by satellite-dependent systems that are necessary to accomplish global earth monitoring and associated studies of the interactions between the earth's atmosphere, land surface, and ocean.

1. Satellites

1.1. New Satellites 1992 - 1993

1.1.1. Polar-Orbiting Spacecraft

In August 1992 the United States (U.S.) and France launched the TOPEX/Poseidon satellite to measure ocean topography. TOPEX/Poseidon uses a radar altimeter to measure sea surface height and in combination with very precise determination of the spacecraft's orbit, the altimetry data will have an accuracy of about 3 cm.

The joint U.S. and Italy Laser Geodynamics Satellite-II (LAGEOS II), designed to reflect laser beams back to ground stations in order to precisely measure movements in the Earth's tectonic plates, was launched in October 1992. Long-term, geographically dispersed measurements will reveal how the plates that make up the Earth's crust are moving.

The U. S. NOAA-13 polar-orbiting satellite was launched in August 1993 and failed to operate shortly afterwards. As a consequence, the Solar Backscatter Ultraviolet (SBUV) instrument on NOAA-9 will be activated to provide ozone data and NOAA-11 and NOAA-12 will continue to provide operational sounding and image data.

The France Systeme pour l'Observation de la Terre (SPOT-3) satellite was launched in September 1993. The satellite provides 10-m resolution and stereo capability to derive digital elevations.

In September 1993 the India Remote Sensing (IRS-1E) operational weather satellite was placed into the wrong orbit.

The U.S. Landsat 6 was launched in October 1993, did not appear in its planned orbit, and its location is unknown. Because satellite trackers have been unable to locate the satellite in any orbit, it has been speculated that the satellite kick motors may have sent it into the ocean rather than to a higher altitude.

The joint France, Germany and Russia Earth Radiation Budget (ScaRab) instrument is scheduled for launch in October 1993 on the Russia Meteor-3 series polar-orbiting weather satellite.

1.1.2. Geostationary Spacecraft

India launched INSAT-2A in 1992 and INSAT-2B in 1993. These satellites carry, along with the communication payloads, a Very High Resolution Radiometer (VHRR) payload for meteorological observations and weather forecasting.

Due for launch in November 1993 is the last of the Meteosat Operational Programme, Meteosat-6, equipped with MVIRI.

1.1.3. Space Shuttle

The U. S. Atmospheric Laboratory for Applications and Science (ATLAS-1) flew aboard the U. S. Space-Shuttle Transportation System in March 1992. This was the first in a series of such spacelabs that will study solar output as well as the chemistry and dynamics of the middle atmosphere over a solar cycle of 11 years. ATLAS-2 recorded data in March 1993.

1.2. Planned Satellites 1994 - 1995

1.2.1. Polar-Orbiting Spacecraft

The U. S. NOAA J satellite will very likely be called up for launch as an afternoon satellite in 1994 because of the failure of NOAA-13. It will be fitted with a SEM, SBUV and AMSU-B instruments. A new series of NOAA polar-orbiters is scheduled for launch beginning in 1996.

Continuity with the European Space Agency (ESA) ERS-1 measurements will be provided by ERS-2, scheduled for launch in December 1994 and equipped with Global Ocean Monitoring Experiment (GOME), Along-Track Scanning Radiometer (ATSR)-2 and PRARE in addition to the ERS-1 instrument suite.

Canada will launch its first earth observation satellite, RADARSAT, in January 1995. It will carry a Synthetic Aperture Radar (SAR), and is designed to provide data for operational applications for five years. Applications include crop monitoring, tropical deforestation, marine activities (including sea state), sea ice distribution, and geomorphological information for mineral exploration.

Launch of a second ScaRab is foreseen for fall 1994 which will provide at least four observations every 24 h which is necessary for sampling diurnal variations.

India will launch an operational weather satellite, IRS-P2, in 1994 - 1995. The satellite will carry a Linear Imaging Self-scanning Sensor (LISS) operating in four spectral bands and a Monocular Electro-optical Stereo Scanner (MEOSS), which is a single optics single spectral band camera that provides stereoscopic imaging.

India is planning to launch a second-generation Indian Remote Sensing (IRS-1C) satellite in 1995. The IRS-1C will carry a high-resolution panchromatic camera (PAN), LISS, and a coarse-resolution camera (WIFS).

1.2.2. Geostationary Spacecraft

The first in a new series of U. S. geostationary satellites, Geostationary Operational Environmental Satellite (GOES)-I, is scheduled for launch in 1994. The separate imager and sounder instruments will provide concurrent measurements as frequently as every six minutes over selected 1000-km by 1000-km areas and soundings on a full-time basis. The GOES-I imager will contain 5 channels in the visible and infrared portions of the spectrum. The resolution of the single visible channel will remain at 1 km, while each of the four infrared channels will show at least a 2-fold improvement. A vastly improved sounding capability will be obtained by increasing the data quantization to 13 bits from the present 10, and by adding six channels for a total of 18. The three-axis stabilized platform will permit the sounder to provide hourly moisture and atmospheric stability, temperature and moisture soundings, and depiction of the boundary layer.

1.2.3. Space Shuttle

The U. S. SIR-C and Italy X-band SAR instruments will both fly on two occasions on the U. S.

Space Shuttle in 1994. The SARs will provide data to interpret geological features, ice processes, biogeochemical and soil moisture processes. The U. S. ATLAS-3 and the Measurement of Air Pollution from Satellites (MAPS) are planned to be used on the U. S. Space Shuttle during 1994.

2. Composite Data Sets

Satellite measurements require continuous correlative in-situ data for validation. Also, because satellite-borne instrumentation can not measure all the important variables, simultaneous in-situ observations are necessary. A selection of interdisciplinary data sets are outlined.

2.1. SAR

To assess the utility of SAR data for the North American Great Lakes ice analysis, the U. S. NOAA established a February 1993 data set, including ERS-1 SAR, AVHRR, U. S. Coast Guard Side Looking Airborne Radar (SLAR), in-situ data consisting of ice charts, aerial photographs and video taken from a helicopter, and meteorological data from ground stations and buoys.

The U. S. NASA produced a CDROM of data from the Bonanza Creek Forest Experiment, which includes AIRSAR, SEASAT SAR, and in-situ measurements of a wilderness area near Fairbanks, Alaska.

To develop a vegetation canopy model for use in interpretation of forest imagery, Canada obtained 1992 - 1993 data at the Petawawa National Forestry Institute near Ottawa. Data included CCD and spectradiometer measurements of the canopy above the tree top, irradiance measurements within the canopy, dielectric measurements of tree components, tree architecture observations, and airborne C-band and X-band SAR measurements.

Canada and ESA obtained a SAREX data set consisting of ERS-1 SAR and airborne C-band and X-band SAR measurements and associated surface ground data in Central and South America and in Europe.

In preparation for the launch and operation of Canada's RADARSAT satellite, a worldwide airborne campaign of SAR data acquisition, referred to as GLOBESAR 93, is presently underway.

Canada recorded a unique airborne C-band interferometric SAR data set in the Kananaskis Valley of Alberta in February 1992. Digital terrain models derived from precise traditional surveys were compared with those derived from the interferometric SAR.

2.2. UARS

The U. S. NOAA records visible-ultraviolet measurements of the nitrogen dioxide column abundance from a mountain-top site in Colorado during overpasses of UARS. These data will provide insight into and calibration-tests of the satellite data.

The European Arctic Stratospheric Ozone Experiment (EASOE) over the winter of 1991 - 1992 has integrated data derived from balloon-borne sondes and from the UARS, and shown that ozone depletion is occurring in the Arctic.

2.3. Satellite Data Reprocessing

The U. S. Pathfinder data reprocessing program will create a new generation of earth-science data sets from previous satellite data by reprocessing them with uniform up-to-date methodologies. The April 1987 - November 1988 Phase I period was chosen because it includes field campaigns, spans several growing seasons, and the satellite sensors were all operating correctly during this

period. Pathfinder data sets include measurements from the Advanced Very High-Resolution Radiometer (AVHRR), TIROS Operational Vertical Sounder (TOVS), Geostationary Operational Environment Satellite (GOES), the Special Sensor Microwave/Imager (SSM/I), the NIMBUS Special Sensor Microwave Radiometer (SSMR), and Landsat Land Cover Change.

2.4 AVHRR

The U. S. NOAA has prepared two CDROMs with data on vegetation, ecosystems, climate, topography, soils, and global vegetation index (GVI).

2.5 Landsat

A map of the United Kingdom has been produced using imagery from the Landsat Thematic Mapper with 25 distinct landcover classes identified.

3. Highlights of Scientific Results

3.1 Middle Atmosphere

One of the major Earth science highlights of 1992 was the discovery that, like the ozone layer over the Antarctic with its well-documented annual depletion, the ozone layer in the Northern Hemisphere is increasingly vulnerable to depletion. Results from the Second Airborne Arctic Stratospheric Expedition (AASE-II), a six-month study of the atmosphere using the NASA research aircraft and UARS data, revealed that during the winter of 1991-92 the Northern Hemisphere had a high concentration of ozone-depleting chemicals in the stratosphere, but early warming in late January precluded major ozone depletion. UARS data also revealed that ozone decreases in the mid-latitudes were associated with increased levels of synthetic chlorine and bromine compounds in the stratosphere.

Trajectory calculations in the Northern Hemisphere suggest that ozone-poor air had originated in lower latitudes. Data from UARS showed very low ozone levels in an area extending from about 10°S to about 20°N, roughly coinciding with the densest part of the Mount Pinatubo volcanic plume, raising the possibility that volcanic eruptions may trigger ozone depletion processes similar to those that occur within the Antarctic ozone hole.

Satellite observations of global distributions of total ozone amount showed that the marked decrease starting in the summer of 1992 had continued into the fall of 1993. SBÙV data on NOAA-11 satellite were among those used to record this record low value. Decreases in total ozone were observed in a large range of latitudes and especially in the Northern Hemisphere mid-latitudes.

Temperature and wind data obtained during the past 20 years from rockets launched by India at Thumba show the presence of quasi-biennial and semi-annual oscillations (QBO and SAO) in the middle atmosphere with large inter-cycle amplitude and phase variations. During the years of easterly QBO phase, SAO amplitudes are lower and these also happen to be the years of deficient annual rainfall establishing the linkages between tropospheric and middle atmospheric dynamical phenomena.

3.2 Lower Atmosphere

NOAA implemented a significant improvement to the TOVS and VAS temperature and humidity products on the NOAA polar-orbiting satellites. A surface air temperature parameter instead of a surface temperature parameter is used when computing the first guess. Improvements occurred for cloudy atmospheres near the surface, and at higher levels in clear atmospheres. In 1993 NOAA

began testing a new VAS Gradient Winds program to produce thermal gradient winds.

ERS-1 SAR imagery with a 240-m resolution is used by the U. S. Navy/NOAA Joint Ice Center in an operational demonstration for ice analysis. Experience indicates that SAR data provides the capability to depict thin ice features and discriminates between multi-year and first-year ice, phenomena not easily observed with the other satellite sensors.

Global observations of cloud properties from satellites are needed to understand the role of the atmospheric constituents in climate change and weather prediction. NOAA has developed remote sensing techniques to provide global measurements of cloud parameters. The TOVS and VAS infrared window and CO_2 absorption band measurements are used to determine an "effective" cloud amount and cloud top pressure. AVHRR data are used to derive total cloud amount and cloud type. A multi-layer cloud amount algorithm will be implemented in 1994. It will determine multiple layers of thin cirrus, low stratus, and deep convective cloud types, and their cloud amount and cloud altitude.

NOAA has determined that imagery derived from digital subtraction of two IR window channels is more effective in detecting fog and low clouds at night than single IR channel techniques. Work continues on image processing techniques and the extraction of fog thickness. The same dual IR imagery also has potential applications in the analysis of aircraft icing, precipitation coverage, and the detection of some tropical storm centers.

NOAA is evaluating the utility of Special Sensor Microwave/Imager (SSM/I) observations in short-term forecasting of moisture near the Gulf of Mexico. Aspects of the atmospheric water budget were examined following intense cold-air outbreaks over the Gulf of Mexico using operational forecast models, and precipitable water and surface wind speed estimated from the SSM/I. The observed rate of moistening was often underestimated indicating deficiencies in the inferred magnitude of flux convergence and evaporation.

Mt. Spurr, located 125 km west of Anchorage, Alaska, experienced three major eruptions in 1992, in June, August, and September. As the eruptions were large enough to pose hazards to aircraft, NOAA collected and analysed all available imagery from the NOAA polar-orbiting satellites and geostationary satellites to determine plume altitude and ash cloud movement. Projected ash cloud trajectories were disseminated to aviation interests. Retrospective data and imagery of the eruptions are available to verify methods of volcano detection using satellite data. In addition to the Mt. Spurr eruptions, similar analyses were made for eruptions of Mt. Bogoslof (Russia), Mt. Akutan and Mt. Mageik (Alaska), and Mt. Pinatubo (Philippines).

3.4 Oceans

Geosat altimeter data showed the variability in sea surface topography off the southern tip of Africa resulting from the interaction of the Agulhas Current with the Antarctic Circumpolar Current. This has been compared with predicted results from the United Kingdom Fine Resolution Antarctic Model (FRAM), allowing refinement of that model.

The period 1992-93 has been especially exciting for the satellite altimetric community owing to the availability of new data from ERS-1, TOPEX/Poseidon, and declassified data from Geosat (1985-86). By means of computer networks, ERS-1 fast-delivery altimeter data are available to NOAA on a daily basis with a delay of only 3-6 hours. After incorporating a precise orbit and other corrections needed for determination of ocean topography, NOAA retransmits the data to institutions around the world for further analysis. These data are used to monitor sea level in the tropical Pacific, with particular emphasis on improving El Niño forecasts. NOAA prepares monthly updates of sea level anomaly and publishes these analyses in the NOAA Climate Diagnostics Bulletin.

Advanced onboard tracking systems together with more accurate gravity models have reduced the TOPEX/Poseidon radial orbit error to approximately 5 cm. The data will be used by oceanographers to calibrate the computer models that help forecast future climate changes. Oceanographers observed an equatorial Pacific Kelvin wave, which is a large warm water mass that moves eastward along the equator in the Pacific Ocean and give rise to El Niño conditions.

Satellite altimetry continues to have an extraordinary impact on the Earth sciences because the sea surface topography measured by radar altimeters can be used to map the gravity field of the Earth. To date, however, only Geosat data have possessed both the accuracy and density of coverage necessary to clearly resolve tectonic details in the marine gravity field on a global basis. The recently declassified Geosat geodetic mission data south of 30°S have had a major impact on marine geophysics and geodesy. As the majority of the world's oceans are located in the Southern Hemisphere, the fine-scale tectonic features of much of the world's gravity field, and hence the sea floor, are viewed for the first time, because the inaccessible Southern Ocean has been only sparsely surveyed by ship. This mapping of the gravity field has resulted in numerous discoveries about the sea floor and underlying crust. NOAA has computed and distributed this gravity field.

NOAA improved its method of computing AVHRR-based sea surface temperature (SST) for the Global Telecommunications System (GTS) transmissions. In the old method, the first SST retrieval found in a grid element since the last transmission was used. The improvement uses an average of all SST retrievals in the grid element since the last transmission.

The capability of satellite remote sensing to provide synoptic, repetitive and multispectral data has proved to be very useful in the inventory and monitoring of coastal features, such as tidal wetlands, coastal landforms, potential aquaculture sites, mangroves, estuary-dynamics/shoreline changes and offshore aspects like suspended sediment dynamics and coastal currents, near-shore bathymetry, and internal waves. Multidate IRS-1A and IRS-1B data has been used to map the entire coastal zone of India on 1:250,000 scale with planimetric and classification accuracies of 90-95%. The project has also led to identifying areas undergoing changes in the shoreline. Some examples are: (i) on the Gujarat cost, depositional processes are predominant in the Gulf of Khambhat except in the Mahi estuary; (ii) in Andhra Pradesh, tidal flats and mangroves are reducing in extent because of reclamation; (iii) the Karnataka coast is marked by spectacular spits; (iv) erosion is noticed north of Madras, while depositional processes prevail at Point Calimere and Nagapattinam.

Through development of appropriate algorithms, it has been possible for identifying various mangrove categories as existing in the Indian coastal zone from multidate satellite data analysis. The dynamics and changes in the mangroves have also been studied to identify the processes related to the same. Such informations are being utilized in conservation of the coastal ecosystem and towards ensuring preservation of the bio-diversity.

3.4. Geology of Land Surfaces

Landsat Thematic Mapper data at optical, infrared and radar wavelengths helped U. S. scientists discover several previously unknown earthquake faults in California's northeastern Mojave Desert. Analysis of the remote sensing images, combined with field observations, indicate that the area is crossed by many young faults.

A relatively new, promising technique for applications in geology, including hazard control, is SAR interferometry. The technique, based on the coherent nature of SAR images, compares the relative phase from two radar images of the same scene. The images may be obtained simultaneously by an aircraft system with two antennas; such a system is operated by NASA as part of the 3-frequency polarimetric AIRSAR. In case of satellites the two images are obtained at separate times from orbits which are closely spaced. In order to achieve coherency the time

interval between the image acquisitions preferably should be just a few days because the surface properties should not change significantly between the acquisitions. The main application of SAR interferometry is topographic mapping with high spatial resolution. The feasibility of mapping crustal movements by means of differential interferometry was demonstrated with ERS-1 SAR data acquired before and after the Landers earthquake in Southern California. The interferogram provides a clear visualization of the movements caused by the earthquake. Potential applications include post-seismic monitoring, erosion monitoring and monitoring terrain movement in volcanic zones. Vertical movements on the order of 1 cm can be detected by differential interferometry. The FRINGE Working Group was set up by ESA to develop and demonstrate interferometric SAR techniques based on ERS-1 data.

Various activities on hazard monitoring and reduction are going on in response to the United Nations designation of the "Decade of Natural Disaster Reduction" (1990-2000). UNESCO, the Netherlands Government, and the Commission of the European Communities (CEC) are sponsoring a programme on "Geo Information for Environmentally Sound Management of Natural Resources". Within this programme, among other topics, methodologies for slope instability hazard zonation are developed using information from high resolution earth observation satellite sensors such as SPOT HRV and Landsat TM. The satellite data were found to be useful for hazard mapping at regional scales, as demonstrated in a pilot project carried out in Colombia.

Data from Indian Remote Sensing Satellites, IRS-1A and IRS-1B, generated up-to-date maps and statistics on land use and land cover. Using the multidate data, the land use and land cover maps for India have been prepared giving details on agricultural lands, forest cover, wastelands, and coastal zones. The corresponding statistics for various land use and land cover classes have been prepared and field verified through random sampling methods. These maps form the basis for agroclimatic zonal planning for improving the productivity of the lands.

3.5 Land and Ocean Productivity

An information access network for Africa has been developed under ESA to improve early warning of food crisis and natural disasters. It makes use of satellite telecommunications to connect FAO Headquarters in Rome with regional offices in Africa. The transmitted data include imagery and derived products from environmental satellites providing information on precipitation and vegetation conditions in Africa. Since several years FAO has been involved in the transfer of remote sensing technology to developing countries to contribute to the solution of problems in various fields such as food security, agricultural productivity, desertification, and tropical forestry.

TREES (Tropical Ecosystem Environment Observations by Satellites) is a joint major project of ESA and CEC to assess and monitor on a long term basis the tropical forests at regional to global scales. During the first phase of the project, which is already completed, AVHRR data were collected and analyzed over the global tropical zone. During the second phase methods are being developed for utilization of SAR data for ecological monitoring of the tropical zone as well as integrated methods based on SAR data and optical imagery. Ongoing investigations are primarily based on ERS-1 SAR data. Final goal of the TREES project is to establish an operational tool for monitoring extent and conditions of tropical forests on a continuous basis.

Significant progress has been made in the understanding of radar backscatter from vegetated surfaces and the development of techniques for the detection of crop type and forest biomass from SAR data. Airborne SAR and scatterometer campaigns, carried out in various test sites in Europe over the 1987-1991 period showed the capabilities of multi-frequency SAR data for crop type discrimination. Though ERS-1 SAR is only a single-channel SAR system, it was found to be useful for separation of crop types if multi-temporal data are used. Interesting results on soil moisture monitoring were obtained with ERS-1 SAR data. The radar backscatter was found to correlate directly with the moisture content of bare soils.

In India, data from IRS-1A and IRS-1B are used in the crop acreage and production estimation (CAPE) program. Information on crop acreage and yield estimation is given one to one and half months in advance of harvest for several purposes such as pricing, movement of grains, and storage. Models have been developed on likely crop yields for different crop regions.

NOAA developed a soil wetness index that uses the difference between the 85-GHz and 19-GHz horizontally polarized data from SSM/I on board the DMSP satellites. The experimental product is extremely useful for monitoring the areal extent of flooding for nearly all weather conditions, excluding actively precipitating areas. This index is also being compared with the Palmer Drought Index and cumulative rainfall.

A NASA study indicated that, while the rate of tropical deforestation is decreasing in the Brazilian Amazon Basin, the overall extent of deforestation and the adverse effects on the topical forest habitat have increased since the late 1970s. Data from the Landsat-4 and Landsat-5 satellites covering 1978-88 indicate that although the extent of deforestation is less than expected, deforestation has increased substantially and created adverse "edge effects" that pose a significant threat to the habitat of plant and animal species. "Edge effects" are the destruction or degradation of natural habitats that occur on the fringes of deforested areas.

The United Kingdom Terrestrial Initiative in Global Environmental Research (TIGER) program is examining carbon fluxes in tropical forests with field campaigns in Brazil. This involves the use of simultaneous AVHRR and SAR to evaluate spatial extent of different regeneration states coupled with in-situ measurements of CO_2 exchange to predict the contribution made by tropical forests on a global scale. These studies complement BOREAS, which has UK involvement in modeling of CO_2 exchange in boreal forests of Canada through coupling of remotely sensed data to ecosystem simulation models.

NASA constructed a 7.5-year time series of global algae biomass from NIMBUS-7 Coastal Zone Color Scanner (CZCS) data. Large interannual variability occurs in oceanic biomass and blooms in the equatorial oceans can be larger than expected and play an important role in controlling degassing of CO_2. The discharge of the Amazon River is carried at least 3/4 of the way towards Africa in the Atlantic Ocean, while the Orinoco River plume dominates the surface variability in the Caribbean Sea. Improved models of regional primary production are based on satellite-derived algae biomass, sea surface temperature, and historical data on phytoplankton physiology.

NASA conducted a series of aircraft flights in August and September 1992 in the equatorial Pacific as part of the Joint Global Ocean Flux Study (JGOFS). An unexpectedly high productivity of microscopic plants occurred near the equator in the Pacific Ocean. Airborne data were linked with observations from the Space Shuttle to guide research vessels to areas of high productivity.

IRS-1A and IRS-1B data in the broad spectral bands of blue, green and red regions have indicated the detection of high chlorophyll concentrations and associated high productivity.

3.6. Pollution Monitoring

Oil spills continue to be monitored with air-borne and satellite-borne instrumentation. The United Kingdom flew an airborne imaging spectrometer to monitor oil spills from the tanker *Braer* in the Shetlands. ERS-1 SAR imagery has indicated its value in detecting and monitoring oil spills.

NOAA uses AVHRR data to observe aerosol optical thickness (AOT) over the oceans. The AOT is derived from cloud-free intensity measurements of reflected solar radiation compared with radiative transfer model results. This product has been particularly useful in monitoring the evolution of the aerosol layers generated by the eruptions of Mt. Pinatubo and Mt. Hudson in 1991.

Global air temperature data obtained from TOVS and Microwave Sounding Unit (MSU) quantified the extensive cooling effects of stratospheric aerosols produced by the 1991 eruption of Mt. Pinatubo. Incident solar radiation is a reflected back to space by stratospheric aerosols. The loss of the warming solar radiation exceeds the smaller amount of infrared radiation trapped by the aerosols, hence resulting in a temporary cooling of the earth.

3.7. Glaciology

Spaceborne observations are particularly important at the Poles, where information is difficult to acquire. Many countries are involved in national and international investigations of ice sheet dynamics. Radar altimeter data are providing precise repetitive measurements of Antarctic ice sheets, which will ultimately resolve their state of flux. Measurements by the Geosat altimeter have revealed surface flow features and reflected underlying topography of the Antarctic landmass; ERS-1 data is providing even better coverage. The International Polar Ice Sheet Program, involving 23 countries in the largest ever comprehensive study of the polar ice sheets, use altimeter, SAR and ATSR data to measure all elements of the mass-balance equation.

4. Contributions to International Programs

Coordination of global change research is achieved on a global scale through both formal and informal mechanisms. A number of the key U.S. global change research programs are coordinated with their counterpart programs in other countries through three major multilateral programs: the World Climate Research Programme (WCRP); the International Geosphere-Biosphere Programme (IGBP) and the Human Dimensions of Global Environmental Change Programme (HDP). These programs are conducted under the aegis of United Nations specialized organizations (e.g., World Meteorological Organization and UN Environment Program), the UN Educational, Scientific, and Cultural Organization's Intergovernmental Oceanographic Commission (IOC), and the non-governmental International Council of Scientific Unions (ICSU). Satellite data are used in all global change investigations. Three examples are described.

GEWEX, a core activity of the World Climate Research Program (WCRP), seeks to improve our understanding and prediction of changes in water recourses arising from climate change. Canada's activity will concentrate on the Mackenzie Basin and will utilize data from SSM/I, AVHRR and Landsat TM.

JGOFS, a core project of the IGBP, seeks to understand the relationship between ocean biology and carbon dioxide and to develop a capacity to predict how these processes will react and contribute to climate change. Data from the polar-orbiting SeaWiFS spacecraft, which is scheduled for launch in 1994, is important to JGOFS investigators because it provides a global picture by removing the temporal and spatial variability of in-situ measurements.

The Boreal Ecosystem Atmospheric Study (BOREAS) is a joint activity of the United States and Canada, and is an activity of the International Satellite Cloud Climatology Project (ISLSCP) and related to the IGBP. BOREAS seeks to improve our understanding, and provide tools for forecasting how the boreal forest and the climate system interact. Remotely sensed data from AVHRR, Landsat TM and MSS, ERS-1, JERS-1 and SPOT will be used.

National agencies with responsibility for space-based Earth observation programs that support global change research coordinate these programs with those of other countries through the informal international Committee on Earth Observations Satellites (CEOS). In December 1992, CEOS approved an updated data policy that aims to provide satellite data from all missions to global change research scientists for the cost of fulfilling the users' requests.

The Committee on Earth Observations (CEOS) Working Group on Data (WGD) now has four technical subgroups to address specific issues in detail: Data Product Format; Catalog; Network; and Auxiliary Data. The WGD Data Product Format Subgroup has developed standard data formats and member agencies have agreed to incorporate them into ongoing data management planning. To further such coordination, a library of accepted formats is maintained. The Catalog Subgroup (CS) coordinated the development of the CEOS International Directory Network with Coordinating Nodes in the Western Hemisphere, Asia, and Europe, and drafted a document which presents guidelines and recommendations by the CS in developing internationally interoperable catalog systems. The Network Subgroup is addressing issues of user-to-user communication using ground-based networking to deliver a variety of data, including catalog (Directory, Guide, and Inventory) information, browse, and quick look imagery, as well as raw data sets or derived data sets. The Auxiliary Data Subgroup, formed in October 1992, will focus primarily on auxiliary data sets in the framework of Earth observations, stressing interaction with CEOS affiliates in special fields of global change research.

5. Public Education and Awareness

One of the major themes of the 1992 International Space Year (ISY) was education. An example of an education and public awareness activity is Canada's interactive Global Change Encyclopedia (GEOSCOPE), portraying the contribution that remote sensing from space can make to the monitoring of global environmental change on earth. The GEOSCOPE project demonstrates to a large number of people around the world, through hands-on experience, that satellite data are of vital importance in monitoring the global environment. The project is also intended to illustrate the profound changes occurring in many parts of the world. The data are available on two CD-ROM optical disks.

6. Summary

Global earth environmental concerns know no national boundary as evidenced by the abundant international cooperation and goodwill of those involved in collection, distribution and analysis of data from satellite-borne instruments. Progress in climate research depends on the availability of a variety of geophysical data sets to describe the boundary conditions and forcing functions of the climate system. The unique perspective from space provides the opportunity for observations well suited for studies of the earth's atmosphere, land and ocean, which are essential components of the climatic system and which remain severely undersampled. Although both satellite- and ground-based recording systems provide essential information for global climate studies, satellite-borne instrumentation yields unprecedented spatial and temporal coverage of the global ocean.

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